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Establishment of an Environmental Control Technology laboratory with a Circulating Fluidized-Bed Combustion System

Quarterly Technical Progress Report
July 1- September 30, 2006

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ABSTRACT

This report is to present the progress made on the project entitled "Establishment of an Environmental Control Technology Laboratory (ECTL) with a Circulating Fluidized-Bed Combustion (CFBC) System" during the period July 1, 2006 through September 30, 2006. The following activities have been completed: the steel floor grating around the riser in all levels and the three-phase power supply for CFBC System was installed. Erection of downcomers, loop seals, ash bunker, thermal expansion joints, fuel and bed material bunkers with load cells, rotary air-lock valves and fuel flow monitors is underway. Pilot-scale slipstream tests conducted with bromine compound addition were performed for two typical types of coal. The purposes of the tests were to study the effect of bromine addition on mercury oxidization. From the test results, it was observed that that there was a strong oxidization effect for Powder River Basin (PRB) coal. The proposed work for next quarter and project schedule are also described.

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1. EXECUTIVE SUMMARY

Construction and erection of the Circulating Fluidized-Bed Combustion (CFBC) Facility were continuing during this period. The steel floor gratings around riser in all level were installed. Three-phase power supply for CFBC system was also installed. Erection of downcomers, loop seals, ash bunker, thermal expansion joints, fuel and bed material bunkers with load cells, rotary air-lock valves and fuel flow monitors is presently underway. Investigation of mercury oxidization effects from bromine compound (HBr) injection using a pilot-scale slipstream reactor was performed for bituminous coal and sub-bituminous coal. From the test results, it was observed that there was a strong oxidization effect when HBr is added to sub-bituminous coal (PRB).

2. EXPERIMENTAL

2.1 Installation of the CFBC Facility

Installation of the circulating fluidized-bed combustor (CFBC) continues during this period. The following progress was made on the design and erection of CFBC Facility:

a) Received Function Generator for simulation of data stream to computer data acquisition and control program generated by digital flow meters used for measuring heat exchanger coolant flow;
b) Received computer suitable for operating all sensor inputs required for operation and control of combustor (former computer had only one PCI slot which was insufficient for our requirements);
c) Received Visual Basic software package for use in developing specific application data acquisition and control computer program with effective user interface;
d) Received Visual Basic software package for use in developing specific application data acquisition and control computer program with effective user interface;
e) Received and installed 10 KVA un-interruptible 120/240 volt power supply used to assure safe control and shut-down of CFBC system controls and actuators in case of an electrical power interruption;
f) Received low coolant safety control for CFBC System coolant system;

g) Received and installed check valves for primary combustion air fans to prevent backflow;
h) Received remainder of communication cables and data interfaces used with data acquisition and control system;
i) Received linear position transducers used to monitor thermal expansion joint movement;
j) Received solid state relays used between data interfaces and various actuators throughout the CFBC System;
k) Received Thermocouple extension wire used for temperature measuring probes throughout the CFBC System;
l) Received Type R thermocouple probe for general application with CFBC System operation;
m) Installed steel floor grating in central portion of each of the combustion tower floors around the CFBC System riser and other components and constructed a cargo lift-way for transporting materials and fuel/bed material to upper floors of the tower;
n) Received ventilation fan for tower cooling;
o) Received solid state relays for power control to bed pre-heater.
p) Completed 480 volt, 400 amp 3 phase power supply installation in tower for CFBC System;
q) Received coolant control valves for adjusting, under computer control, the flow of coolant through each combustor heat exchanger;
r) Received the remainder of components fabricated by Sterling Boiler and Mechanical; and
s) Continued the erection of downcomers, loop seals, ash bunker, thermal expansion joints, fuel and bed material bunkers with load cells, rotary air-lock valves and fuel flow monitors.

Figure 1 shows a photograph of bunkers. Figure 2 shows a photograph of one segment of the riser.

2.2 Experimental Study of Bromine Compounds Addition on Elemental Mercury Oxidization Effect with a Pilot-Scale Slipstream Reactor

A concept has been advanced that uses the direct addition of chemicals, such as bromine compounds, into flue gas to significantly enhance the mercury (Hg) oxidation (from Hg(0) to Hg(2+)) and also its bonding to fly ash (Hg(P)). However, the mechanisms of bromine addition on the transformation of speciated mercury and its functional temperature window under flue gas atmospheres of different coals are not well understood. It was reported that the possible reaction pathways of mercury and halogen species, including bromine species, under atmospheric conditions are atmospheric photochemical reaction mechanisms, which can not be directly extended to the high temperature environments typical of coal-fired utility boilers. Mercury chemistry is highly dependent upon its interaction with fly ash and some unknown species in the flue gas. As a result, there are significant benefits to conducting the tests using “real” flue gas. This study attempts to answer several questions concerning mercury speciation chemistry under bromine addition using a pilot-scale slipstream reactor system employing real flue gases. Two test series, one burning bituminous coal and the other burning sub-bituminous coal, were selected.

Figure 1. Photograph of bunkers.

A pilot-scale slipstream reactor has been designed and manufactured to simulate the "full-scale" operation of a selective catalytic reduction (SCR) system and air-preheater (APH) in utility boilers. Its two components, SCR reactor and cooling pass (CP) in sequence, are connected by U-shape section on the bottom. The real flue gas passes through the slipstream reactor, first the SCR reactor and then the CP system. An induced (ID) fan, which is located at the outlet of the CP, generates the negative pressure required to induce flue gas from the economizer outlet of boiler. The flue gas then passes through the SCR and CP. The ID fan then delivers the flue gas back to the economizer outlet. The schematic of experimental setup is shown in Figure 3.

The slipstream reactor is fabricated in a concentric configuration for purpose of providing good insulation to minimize the temperature drop inside the SCR reactor to less than 30^{o}C. The flue gas is split into two streams. The ratio of the split is controlled by manual flashboard valves that adjust the section area of the outside flue gas pass. The bypassed flue gas functions as “strengthened” heat insulation due to its higher temperature which minimizes the heat transfer rate by decreasing the temperature difference between the main stream of flue gas which is fed to the SCR reactor and the bypassed flue gas stream. The average temperature inside the SCR reactor is varied between 300^{o}C and 350^{o}C dependent on the load of the power plant. There are two sampling ports in the SCR reactor, one at its inlet and the other at its outlet. In this study, the SCR reactor is not loaded with SCR catalyst, and the CP is bypassed. The mercury continuous emission monitor (CEM) was used for monitoring mercury variation during HBr addition tests. The Ontario Hydro (OH) Method was also used for Hg-CEM data validation. For both methods, an inertial sampling probe was used for the sampling of flue gas.

Gas from a pressurized cylinder containing a pre-determined concentration of HBr in nitrogen as the carrier gas was injected into the system. The desired spiking concentration of HBr inside slipstream reactor can be adjusted by mass flow controller (MFC). To ensure the control and even distribution of HBr addition, three static mixers are installed at different locations of the SCR reactor. The HBr injection port was located below the sampling port at SCR inlet. In this study, the addition concentrations of the HBr injected into the flue gas were controlled at about 3 ppm, 6 ppm, or 15 ppm to minimize potential hazards. The analysis of the coal used and ash produced is shown in Table 1.

Figure 2. Photograph of one segment of the riser.

3. RESULTS AND DISCUSSION

3.1 Effects of HBr Addition on Mercury Transformation for Bituminous Coal

The variation of speciated mercury as monitored by the Hg-CEM system is shown in Figure 4. The figure shows the results of two tests of HBr addition at 3 ppm under a bituminous coal atmosphere. Before HBr addition started, the baseline test was conducted until the speciated mercury concentration stabilized within a variation of 10%. The baseline tests indicated Hg(0)/Hg(VT) was about 55% at the SCR inlet and 40% at the SCR outlet. This result is typical of mercury speciation at a higher temperature of about 300^{o}C for bituminous coal with a high chlorine content. In the 1st trial of HBr addition at 3 ppm, Hg(VT) at SCR outlet remained constant. There was no evidence to show that HBr addition impacted the adsorption of the speciated mercury on fly ash in the flue gas at a temperature around 300^{o}C. However, Hg(0) /Hg(VT) decreased dramatically starting from its baseline concentration at about 40% to about 18% during the time that HBr addition proceeded. The concentration of Hg(0) can be brought back to its baseline level when HBr addition stopps. But this recovery process was slow and required several hours occur. Some “memory” effect of HBr addition seemed to be present in the slipstream reactor after HBr addition was stopped.

For data validation, a confirmation test with HBr addition was conducted in the 2nd trial at the same HBr addition concentration of 3 ppm. Different from what was observed in the 1st trial, Hg(VT) underwent a decrease of almost 50%, large fluctuations were also observed along with a simultaneous decrease of Hg(0) concentration. It appeared that the adsorption of speciated mercury occurred somewhere in sampling system. The sampling probe and analytical system was purged and cleaned during HBr addition period. Hg(VT), but not Hg(0) were recovered back to their baseline levels until the probe , the Hg(VT) varied and can not be back to its baseline level automatically until probe was purged. The “memory” effect of HBr addition was observed after HBr addition stopped. A failure of the heating system resulted in a temperature drop in some parts of the inertial sampling probe during the 2nd trail of HBr addition. Deposition of fly ash was also found inside the inertial sampling probe. Moisture condensation likely occurred and subsequently resulted in fly ash deposition in some parts of inertial probe after temperature drop. It appeared that low temperature can greatly impact mercury adsorption on the fly ash under conditions of HBr addition, which resulted in measurement bias in the 2^{nd} trial of this study.

3.2 Effect of HBr addition on mercury speciation for PRB coal

The variation of speciated mercury at different HBr addition concentrations for PRB coal is presented in Figure 5. The length of baseline tests was determined by the point at which the speciated mercury concentration stabilized to within a 10% variation of the concentration prior to HBr addition. The baseline tests indicated Hg(0)/Hg(VT) varied between 70% to 80% in the flue gas, which is the typical mercury speciation for PRB coal with lower chlorine content. The tests employed an HBr addition of 15 ppm, The results show that Hg(VT) at the SCR outlet followed the same trend of Hg(VT) at the SCR inlet and remained almost const. There is no apparent evidence to show that HBr addition could impact mercury adsorption on the fly ash under a PBR coal atmosphere. The strong effect of HBr on mercury oxidation was found because Hg(0) underwent a dramatical decrease by about 70% compared to its baseline concentration after HBr addition started. The recovery of Hg(0) to its baseline level was slow and took several hours after HBr addition stopped.

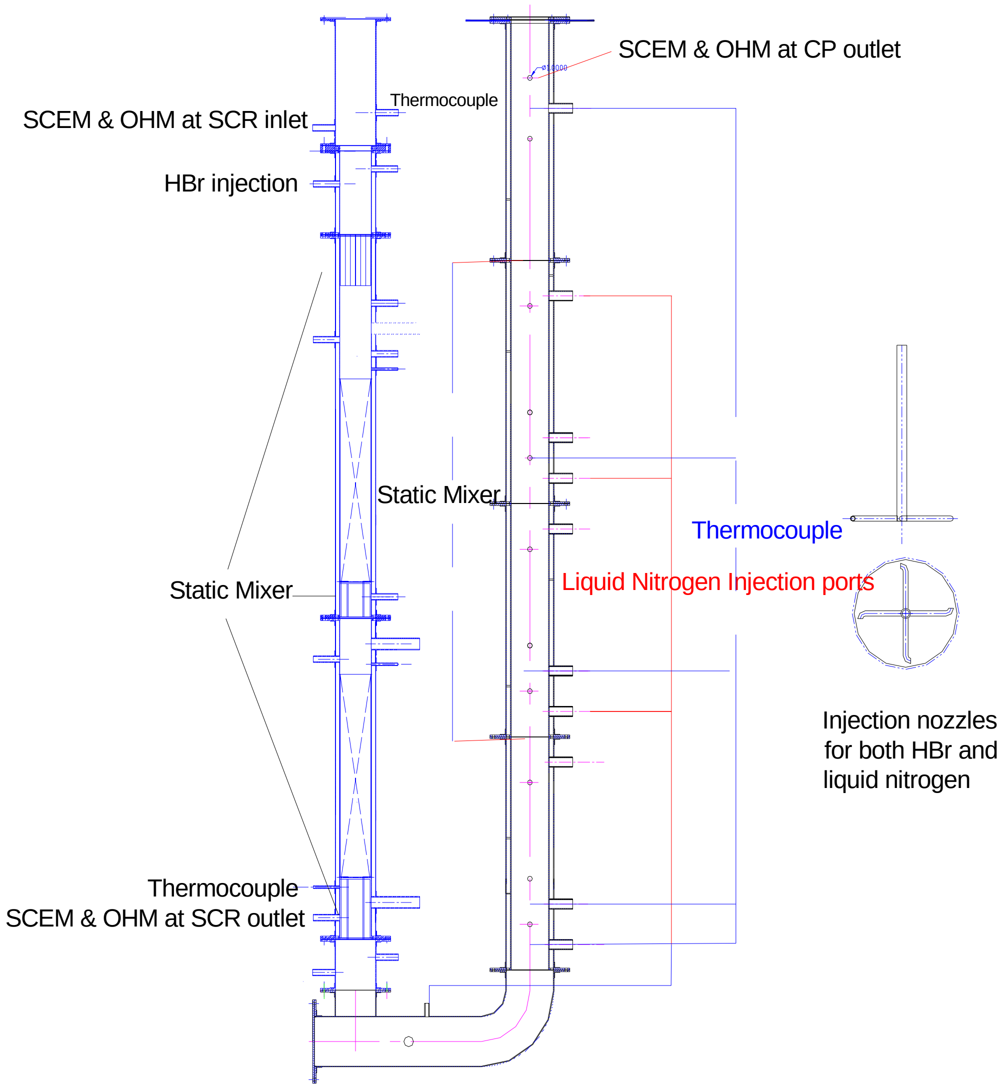

Figure 3. The schematic of a pilot-scale slipstream reactor in coal-fired power plant

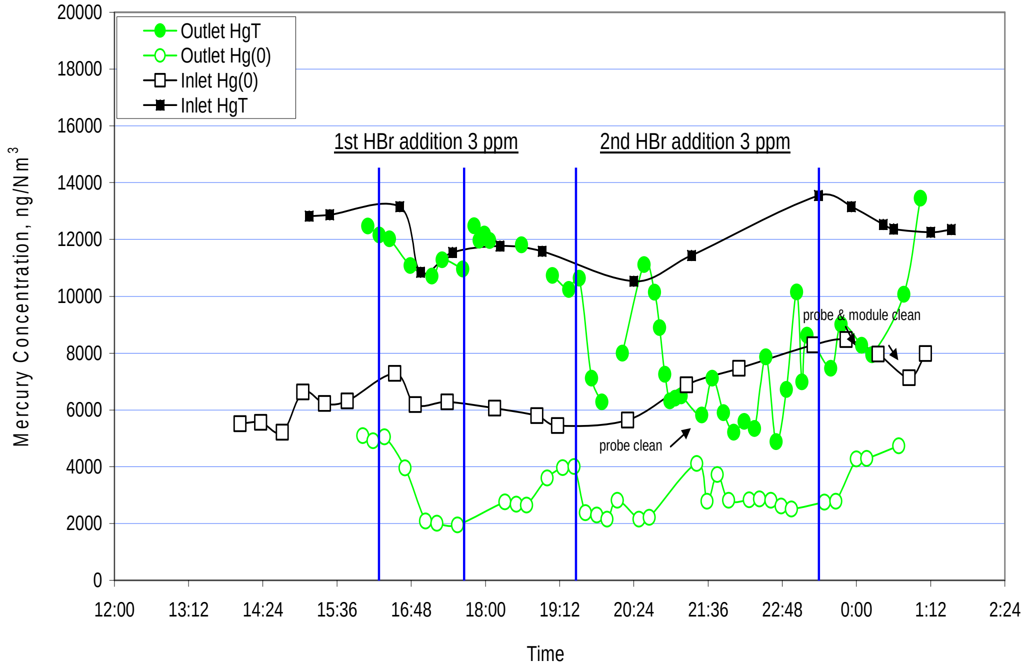

Figure 4. The effect of HBr addition on mercury speciation in a slipstream reactor for typical bituminous coal (HBr addition Trial#1 at 3 ppm, Trail#2 at 3 ppm)

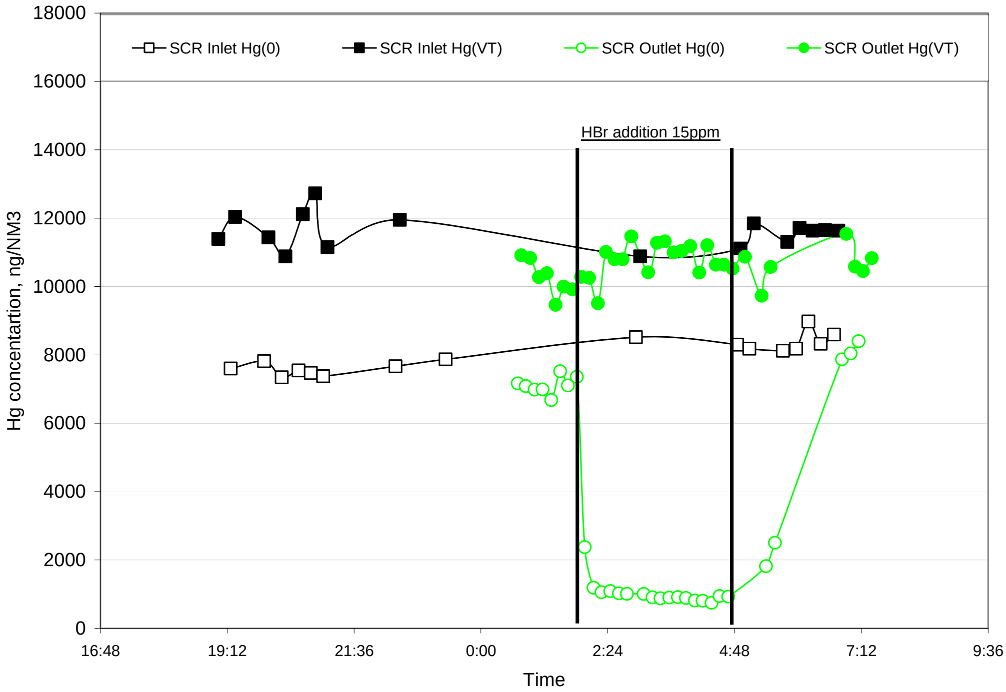

Figure 5. The effect of HBr addition on mercury speciation in a slipstream reactor for typical Powder River Basin (PRB) coal (HBr addition Trial#1 at 15 ppm)

Table 1. Analysis of coal and ash samples during the tests

Coal analysis

	As Determined		Dry Basis										
SampleName	ADL[1] %	Moisture %	Ash %	Vol. Mat %	Sulfur %	Btu BTU/lb	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Chloride ppm	Flouride ppm	Mercury ppm
Bituminous Coal	3.04	5.41	10.30	37.13	1.31	13423	75.85	4.85	1.79	5.92	1328	ND	0.11
PRB[2] CoalTrial-1	20.75	11.37	6.20	47.07	0.42	12022	70.75	5.00	2.21	15.43	177	42	0.07
PRB[2] Coal Trial-2	18.52	12.15	7.59	45.45	0.81	12173	71.15	4.99	2.32	13.15	164	40	0.09
Average	19.63	11.76	6.89	46.26	0.61	12097	70.95	4.99	2.26	14.29	170	41	0.08

	Na_2O %	MgO %	Al_2O_3 %	SiO_2 %	P_2O_5 %	SO_3 %	K_2O %	CaO %	TiO_2 %	MnO %	Fe_2O_3 %	BaO %	SrO %
Bituminous Coal	0.01	0.90	18.14	38.27	0.58	1.94	2.35	1.71	1.14	0.02	17.51	0.15	0.13
PRB[2] Coal	1.02	4.70	14.89	28.63	0.69	11.93	0.39	22.95	1.17	0.02	4.91	0.49	0.30

Ash analysis

SampleName	Sulfur %	Mercury ppm	Chloride ppm	Bromide ppm	Fluoride ppm	LOI %
Bituminous Coal	0.15	0.35	250	ND	ND	7.13
PRB[2] Coal Trial-1	0.67	0.15	123	ND	95	0.59
PRB[2] Coal Trial-2	0.89	0.18	177	ND	98	0.69
Average	0.78	0.17	150	ND	97	0.64

Note:

ADL[1] - air dry loss

PRB[2] - Powder River Basin coal

4. CONCLUSIONS

During this quarter, the following progress has been made:

- The steel floor grating around riser in all level was installed.
- The three-phase power supply for CFBC Facility was installed and energized.
- The erection of downcomers, loop seals, ash bunker, thermal expansion joints, fuel and bed material bunkers with load cells, rotary air-lock vales and fuel flow monitors was initiated; and
- The pilot-scale slipstream reactor study of the effect of bromine compound injection on mercury oxidization was performed on two types of coal. It was observed that there was a strong oxidization effect for PRB coal.

5. FUTURE WORK AND UPDATED SCHEDULE

5.1 Future Work

During the next quarter, work will focus on the following activities:

- Continue installation of the CFBC Facility, including the bubble cap/distributor plate, downcorner, thermal expansion joints, flue ducts, loopseals, and thermal insulation;
- Order and install the I.D. Fan and variable speed drive;
- Order and install the secondary combustion air supply blowers, variable speed drives, and power supplies;
- Order and install the bed preheater/ignition system and controller;
- Order and install the entire cooling system internal loop;
- Order and install the water treatment system for providing supply of cooling water; and
- Continue pilot-scale slipstream reactor testing to investigate mercury oxidization effects of various parameters.

5.2 Project Schedule

Based on the current status of the project, the project schedule for the remainder work is shown in Table 2.

Table 2. Project schedule

Task	Schedule
Complete the installation of the CFBC Facility	December 31, 2006
Complete the installation of the process control and measurement system of the CFBC Facility	December 31, 2006
Based on the experimental data obtained from the laboratory-scale CFBC Facility, determine the investigation of the optimal conditions for co-firing waste materials with high sulfur coals in the CFBC Facility.	November 30, 2006
Complete the study to determine the effect of air staging, fuel feeding position, and limestone feeding on the	February 15, 2007

gaseous emissions in the CFBC Facility.	
Complete the investigation of mercury emissions from co-firing of waste materials with high sulfur coal in the CFBC Facility	April 30, 2007
Submit final report	September 15, 2007

ACRONYMS AND ABBREVIATIONS

CFBC	Circulating Fluidized-Bed Combustion
DOE	U.S. Department of Energy
ECTL	Environmental Control Technology Laboratory
Hg	Mercury content (ppm)
Hg (0)	Elemental mercury
Hg (VT)	Total mercury (elemental plus oxidized mercury)
Hg (P)	Particulate-bond mercury
OHM	Ontario Hydro Method
SCEM	Semi-continuous emission monitor
ISCET	Institute for Combustion Science and Environmental Technology